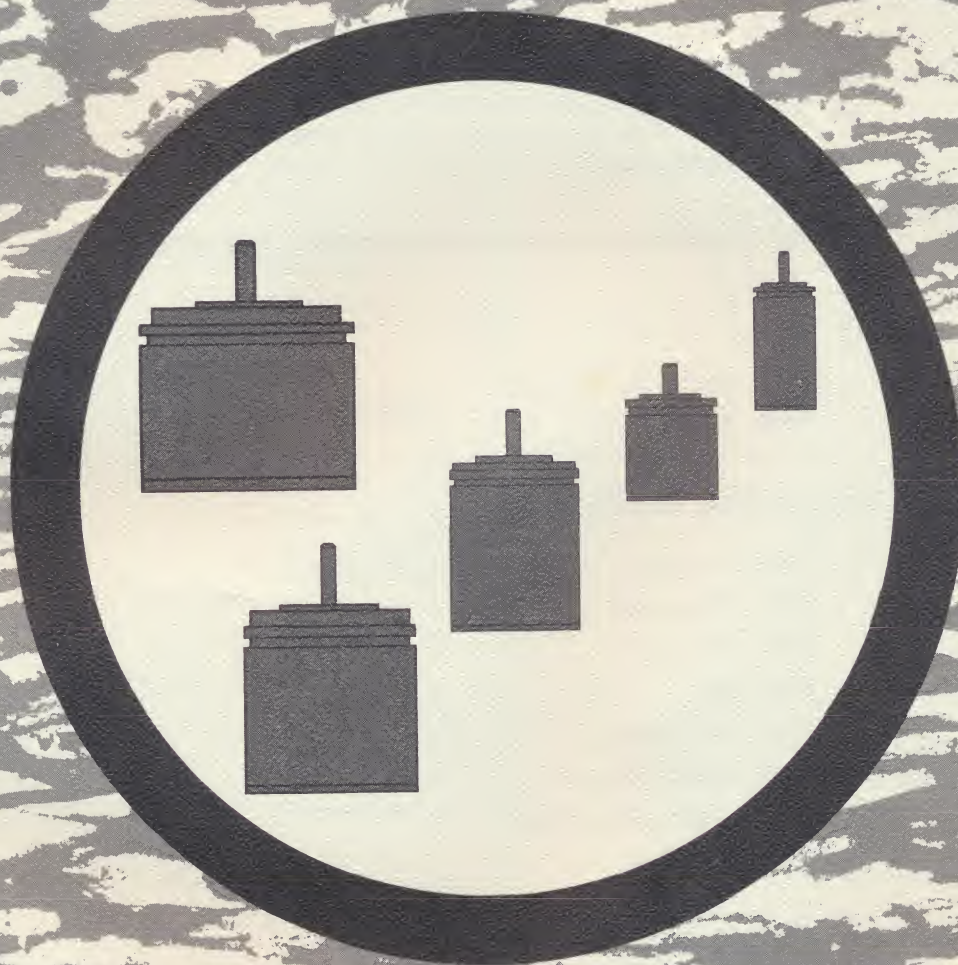


DESIGN AND APPLICATION

STEPPER MOTORS



AMERICAN ELECTRONICS, INC.

FULLERTON, CALIFORNIA

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1.0 INTRODUCTION

1.1 Definition

The stepper motor is a power device in which a drive shaft is caused to deliver mechanical power incrementally in discrete predetermined angular steps in synchronism and in a corresponding direction with a programmed electrical power supply of direct current square wave impulses of a given frequency, direction, amplitude and duration.

1.2 Intent

Its intent is as a simple, reliable and economical link in a servo system which may dispense with the requirement for complex feedback, stabilizing circuitry and the attributes connected therewith.

1.3 Function

Its function is to serve, (a.) as a driving and positioning means in instrumentation systems (as recording pens, indicating pointers, potentiometers, balancing devices, remote indicators digital to analog conversion, etc.) (b.) as a driving and positioning means in production equipment (as table setting in machine tools, setting of welding tips, valve setting, etc.) (c.) as a drive mechanism in tape recording devices (d.) in various computer applications (e.) in data plotting boards and in data or map display devices (f.) as an operating element in control functions (g.) as a pulsing and/or switching element, and (h.) in many sundry applications. It can also be used as a simple driving motor from a DC supply source where brushless operation is a desirable feature.

1.4 Qualities

The stepper motor displays the indigenous qualities of rapid acceleration, stopping and reversal, maximum instantaneous assumption of load, low velocity before gearing, low moment of inertia of rotor, non-cumulative positioning of error, adequate holding torque to prevent drift, no preferred null position, and brushless operation.

1.5 Mode

Inherently, the stepper motor receives successive DC electrical impulses and sequentially energizes an electromagnetic system resulting in a magnetic force which interacts with a magnetic element mounted on the drive shaft; thus effecting an incremental angular movement of the power drive shaft in exact synchronism and direction with the incoming signals.

1.6 Categories

In general, there are two major categories of stepper motor systems. These are characterized by the following mode of operation. One of these categories utilizes the linear unidirectional movement of a solenoid plunger (or armature) which is translated to an angular movement of the drive shaft through an intermediary mechanical system (ratchets, escapements, indenters, etc.) These can be generally termed as electro-mechanical unidirectional devices and generally require two elements for reversibility of drive shaft.

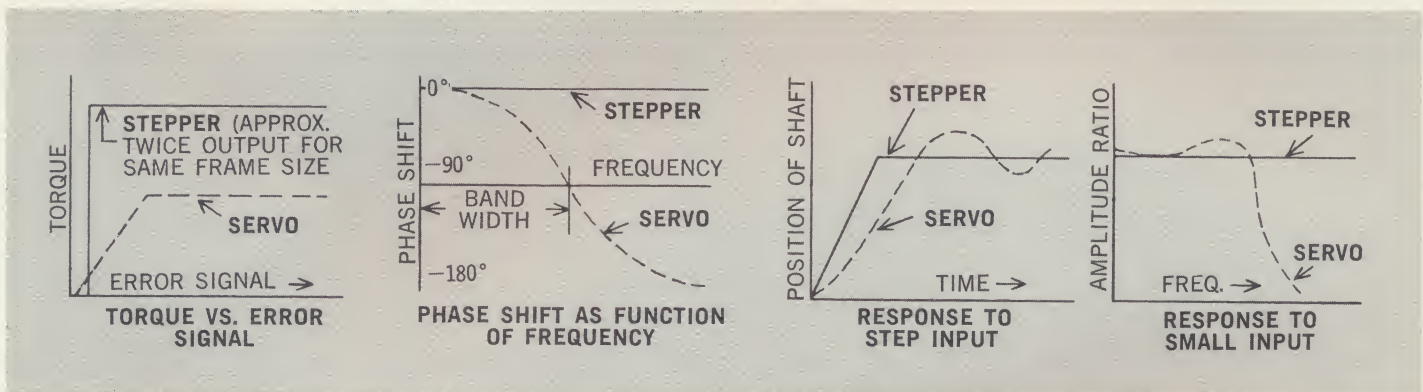
The second category involves the use of an electromagnetic system which is concentric and circumferential with the magnetic element which is mounted on the drive shaft. The magnetic field produced by the electromagnetic system is sequentially rotated around the axis and alternately changed in direction in accordance with the programmed electrical impulses delivered to the motor. Thus the interaction between the magnetic impulses of the field and the magnetic element on the shaft produces an incremental impulse-type angular stepping action of the shaft and delivers mechanical power accordingly. These motors can be generally termed as electromagnetic bidirectional stepper motors. They require only one element for reversibility and are devoid of any intermediary translating mechanism.

1.7 Advantages

The electromagnetic bidirectional motor presents the following advantageous features vis-a-vis the electromechanical unit. The electromagnetic bidirectional motor is smaller, more compact, simpler in design, devoid of intermediary mechanism, and requires less electrical power for its operation. It is capable of response to much higher frequency of electrical impulses; it is less subject to environmental conditions; and it is more reliable.

1.8 Servo Applications

For servo applications the stepper motor presents decisive advantages vis-a-vis conventional servo systems. Synthesized proportional control in servo application is accomplished with suitable AEI stepper—logic combinations. The relative performance, as a general approach, between the stepper-logic combination and the conventional servo systems is vividly indicated in the following curves.



2.0 AEI — ELECTROMAGNETIC BIDIRECTIONAL STEPPER MOTORS

2.1 General

AEI electromagnetic bidirectional stepper motors are precision built, compact, all enclosed, cylindrically styled units. They are generally provided for servo-ring mounting with adequate pilots for location and alignment. The best materials are employed and processed to obtain optimum performance and adequate protection against corrosion, fungus, and electrical noise interference.

The motors are built in a variety of sizes to meet a variety of applications. Although the data sheets provide "standard" designs, a variety of modifications in each size range are available and can be supplied to meet specific installation and application requirements. These modifications include; operating voltage, power delivery, length of unit, mounting means, length of leads and terminations, length of shafts, types of shaft outputs (plain or with suitable pinions), and such other variables as occasion may demand.

2.2 Types

Two types of electromagnetic bidirectional stepper motors are supplied by AEI. These are as follows:

2.2.1 Permanent Magnet (PM) Type Motors (Designated Model "T")

These motors utilize a permanent magnet of suitable quality and proportion as the acting element on the drive shaft. In this formulation the magnetic force of the electromagnetic stator—created by the incoming DC pulse—interacts with the magnetic force of the permanent magnet to provide the incremental step of angular motion of the shaft. By successively shifting the electromagnetic field radially with the stator, both in position and in direction, the shaft, by virtue of the permanent magnet mounted thereon, will follow the electromagnetic field both in position and in direction. The driving and detent torque is obtained as the permanent magnet aligns itself in the electromagnetic field produced by the stator when the latter is energized electrically.

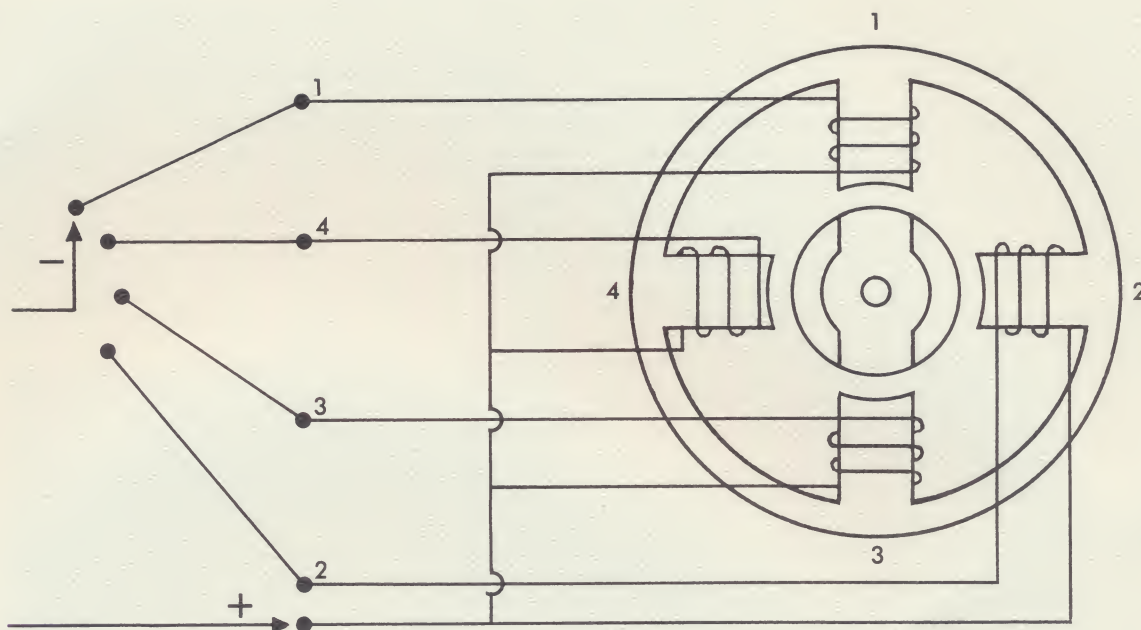


Figure 1

In its simplest form, the "T" motor is illustrated in Figure 1 and its equivalent circuit diagram is shown in Figure 2.

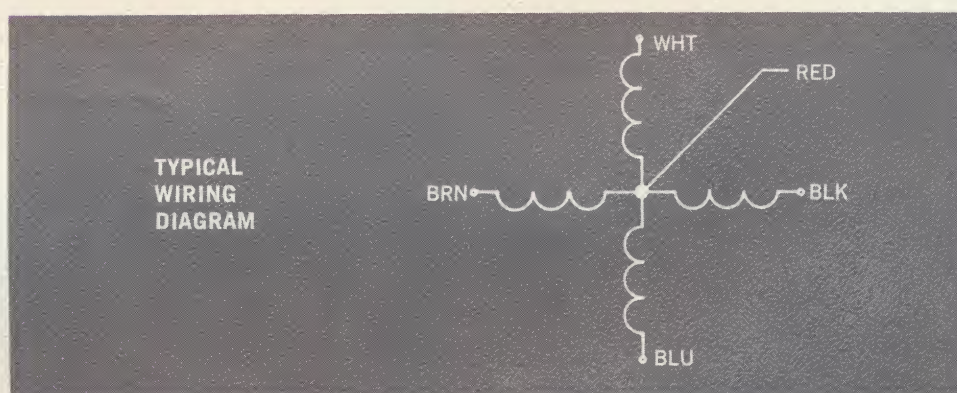


Figure 2

When winding No. 1 is energized, the magnet will align itself with No. 1 pole, and under the influence of the current in the winding, will remain so aligned. Subsequently when dc power is switched from winding No. 1 to winding No. 2, the rotor will instantly move to and will align itself with pole No. 2, moving 90° in a CW direction. Conversely, when dc power is switched from winding No. 1 to winding No. 4, (assuming the rotor having been initially in No. 1 position) the rotor will instantly move to and align itself with pole No. 4 moving 90° in a CCW direction. By exciting two (2) adjacent windings simultaneously (as for example No. 1 and No. 2) a vector sum of the two fluxes will result and the PM rotor will move 45° in CW direction to align with this resultant flux.

Hence, sequentially switching the power pulses to 1-2-3-4 will incrementally advance the rotor in a CW direction; while switching the pulses in the order 1-4-3-2 will advance the rotor in a CCW direction.

2.2.2 Variable Reluctance (VR) Type Motors (Designated Model "S")

These motors utilize a ferromagnetic non-retentive multi-toothed rotor of suitable quality and proportion as the interacting element that is mounted on the drive shaft. In this formulation, the magnetic force of the electromagnetic stator — created by the incoming dc pulse — exerts a pull on the nearest rotor teeth and causes the rotor (and the shaft) to advance in a direction and to a point where minimum magnetic reluctance (hence minimum air gap) is established of the overall magnetic path between the stator and rotor. At this point the maximum retentive force is created on the rotor. In this case, also, as the stator electromagnetic field is successively shifted radially around the rotor, a torque is created on the shaft which moves it to a position of corresponding alignment between the rotor teeth and stator teeth to the criterion of minimum magnetic reluctance of the magnetic path.

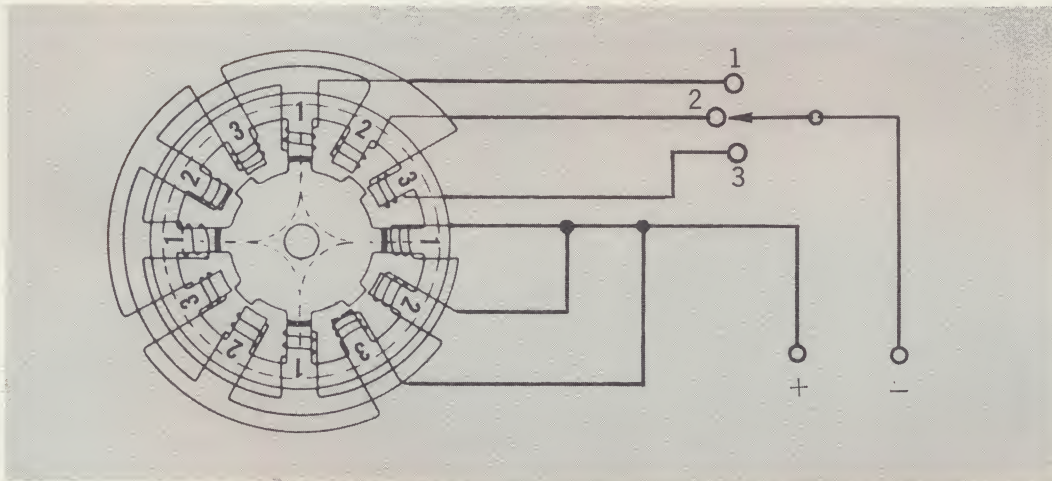


Figure 3

Figure 3 illustrates the mode of operation of the "S" stepper motor using a 3-phase Y corrected winding, schematically indicated in Figure 4. As shown in Figure 3, the rotor is aligned for minimum reluctance with poles No. 1 — assuming phase 1 to be energized.

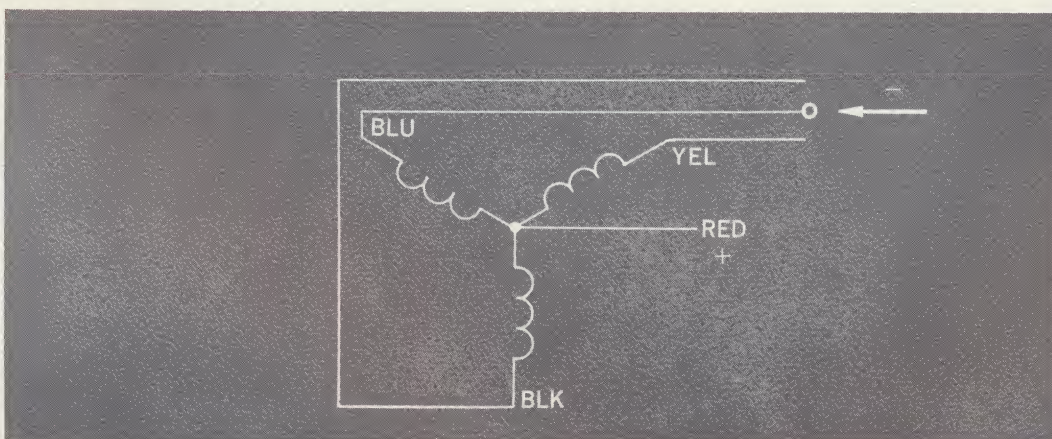


Figure 4

When the pulse is now switched to phase 2, the rotor will advance CCW by 15° until the corresponding rotor teeth align themselves with poles No. 2 for minimum reluctance. If now the pulse is switched to phase 3, (assuming the initial alignment with pole 1), then the rotor will advance CW by 15° until the corresponding rotor teeth will align with the No. 3 teeth. In this manner the rotor may be caused to rotate in CCW or CW directions by successive excitation of the respective phases in the corresponding directions.

3.0 GENERAL PERFORMANCE CONSIDERATIONS OF ELECTROMAGNETIC BIDIRECTIONAL STEPPER MOTORS

3.1 Mixed Program

The previous discussion describes the general performance and operation of the electromagnetic bidirectional stepper motors. Their high torque to inertia ratio, combined with relatively low inductance (time constant) of the windings permits the incremental impulse-type angular movement of the operating shaft bidirectionally in response to, and in complete agreement with, a mixed program of forward and reversed command dc electrical signal impulses as obtained from an appropriate source. However, pragmatic considerations of design and fabrication delineate general limiting parameters as areas of best performance for each type of motor. Obviously, these parameters will vary with varying sizes and modifications of motors. Within the zones of reversibility, the parameters to be considered are as follows for comparable motor sizes.

3.1.1 Step Angle

The "step angle," (the incremental angular deflection per electrical impulse) is usually smaller in the "S" type, than in the "T" type motor.

The "step angle" is determined by the relative combination of the number of teeth (or poles) on the stator and the number of poles (or teeth) on the rotor.

For the "T" type motors, the popular step angle is $45/90^\circ$.

For the "S" type motors, the popular step angle is 15° .

3.1.2 Windings

The type of windings used in these motors are, generally, 2-phase, 3-phase, and 4-phase.

For the "T" type motors, the most usual windings are a) 2-phase (with or without center tap) and b) 4-phase. For the "S" type motors, the most usual windings are a) 3-phase and b) 4-phase.

3.1.3 Response Rate

The "maximum response rate" to the frequency of incoming electrical dc pulses, in pulses per second (pps), of the motors within the zone of reversibility, varies for the different types and sizes of motors and nature of modification.

In general, the "S" Types have a much higher response rate than the "T" Types.

In general, the range of "Maximum Response Rate" for the different types and sizes of stepper motors within the zone of reversibility are as follows:

for "T" Motors — 100 to 280 pps

for "S" Motors — 750 to 1500 pps

3.1.4 Stall Torque

The stall torque of the stepper motors at rated voltage varies with the size of the motor resistance of winding and pertinent modifications. In general, the maximum stall torques for the different size motors are approximately as follows:

	<u>"T" Types</u>	<u>"S" Types</u>
for Size 5 Motors	0.35 in. oz.	0.25 in. oz.
for Size 8 Motors	1.2 in. oz.	0.75 in. oz.
for Size 11 Motors	2.2 in. oz.	3.2 in. oz.
for Size 15 Motors	4.5 in. oz.	6.0 in. oz.

3.1.5 Running Torque

The maximum running torque of the stepper motors is a function of the allowable stepping rate.

In general, an adequate approximation is to consider the running torque to be about one-half ($\frac{1}{2}$) of the stall torque.

3.1.6 Outline Dimensions

Figure 5 illustrates typical outline dimensions for standard stepper motors.

Separate outline drawings are provided where modifications are made to customer requirements as regards to length, leads, type of shaft, shaft extension, mounting means, etc.

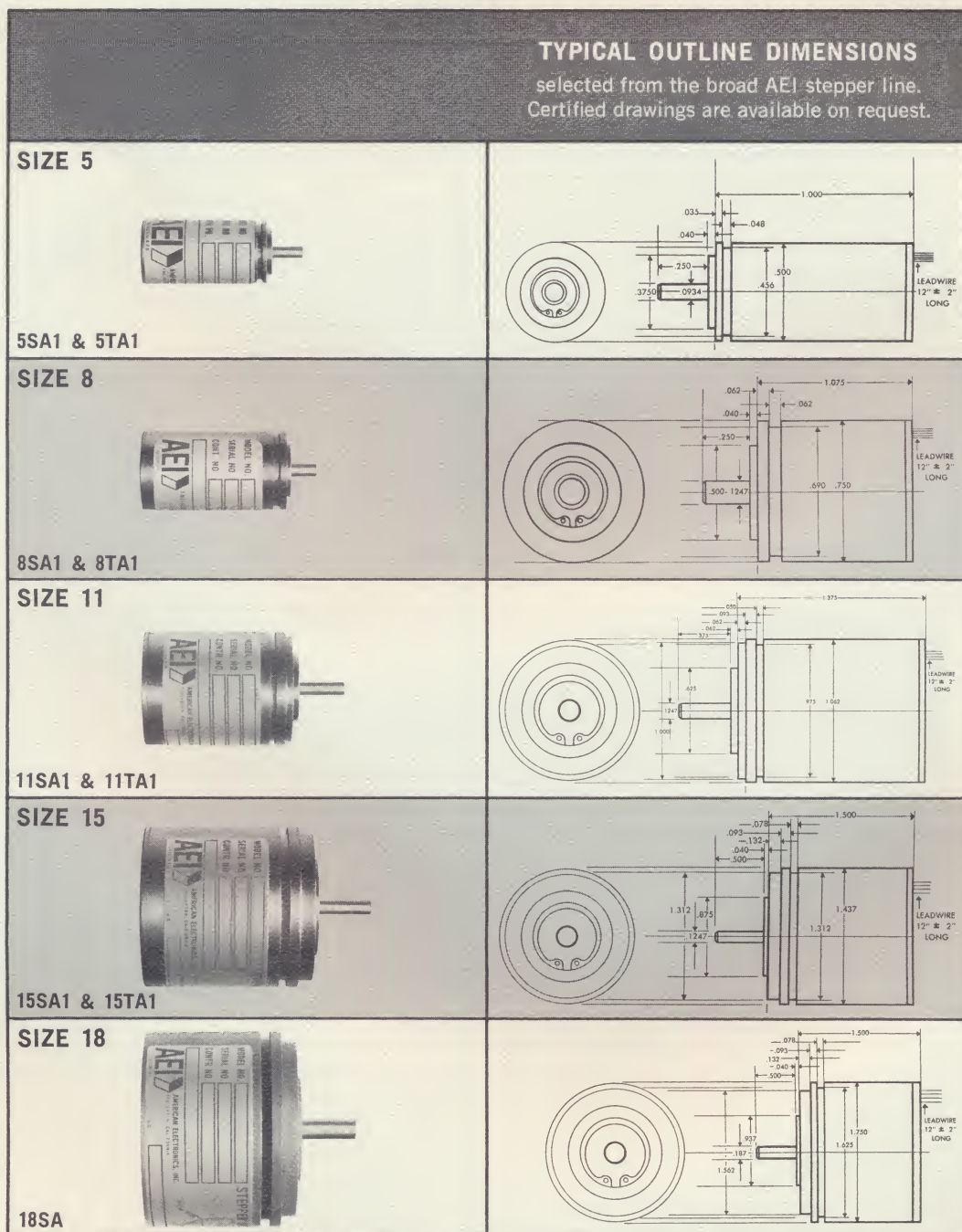


Figure 5

3.1.7 Slew Rate

In addition to its ability to respond bidirectionally to forward and reverse commands, the step motor may be made to step unidirectionally at speed rates far in excess of the maximum bidirectional response rate.

The area above the maximum bidirectional response rate is known as the "slew" rate.

The "slew" rate varies for different sizes and types of motors. As a general rule the "slew" rate may be 2 to 3 times the maximum bidirectional rate. (Under certain conditions the slew rate may exceed these limits.) In the "slew" zone the stepper motor pulls into synchronism and runs continuously. Its operation remains synchronous with the metered pulse train. Its uninterrupted instantaneous angular velocity is still controlled by on-off pulse commands which it can follow (within limits of acceleration and decelerations) without misstep or ambiguity.

In order to return the motor for bidirectional operation, the response speed must be reduced to approximately one-half the maximum response speed for bidirectional operation.

4.0 AEI ACCESSORIES

4.1 Logic Controls

The input requirements of stepping motors require, especially the upper pulse rates, that pulses be adequately shaped and amplified before they are sequentially distributed to the stator windings. AEI offers standard well proven transistorized logic packages designed to meet the characteristics of the stepper motors and intended to produce acceptable output performance under defined load conditions. These logic packages will respond to any digital signal source where the frequency of the pulses are established to meet the desired stepping rate of the motor.

Logic control packages are available for both the 3-phase and the 4-phase types of stepper motors. The logic packages are available in various modifications and are designed to meet the proper impedance of the stepper motors during the "on" period.

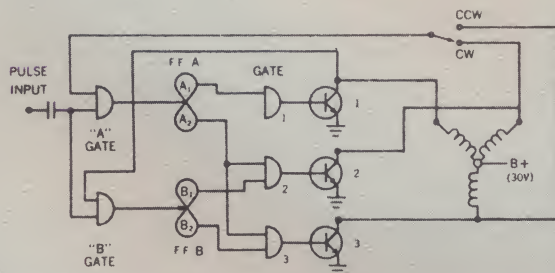
The essential circuitry for the two types of logic controllers is illustrated in the following drawings.

Figure 6 shows the essential circuitry of the 3-phase controller and its connection of the 3-phase stepper motor. (type 1SF6)

Figure 7 shows the essential circuitry of the 4-phase controlled and its connection to the 4-phase stepper motor. (type 1SF1&2)

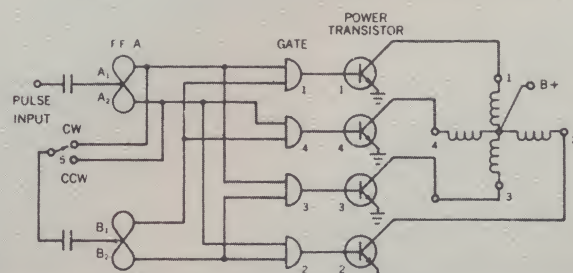
Control of the three power stages (and hence the three motor windings) is determined by the state of the power transistors in the following manner:

Flip-Flop State	Power Stage Condition
A	Transistor #1 is ON
A B	Transistor #2 is ON
A B	Transistor #3 is ON



Control of the four stages (and hence the four motor windings) is determined by the states of flip-flops A and B as follows:

Flip-Flop State	Power Stage Condition
A B	Transistor #1 is ON
A B	Transistor #2 is ON
A B	Transistor #3 is ON
A B	Transistor #4 is ON



The outline dimensions of the type 1SF6 and type 1SF1&2 logic controllers are shown in Figures 8 and 9 respectively. Other configurations of controllers are available to meet customer demands.

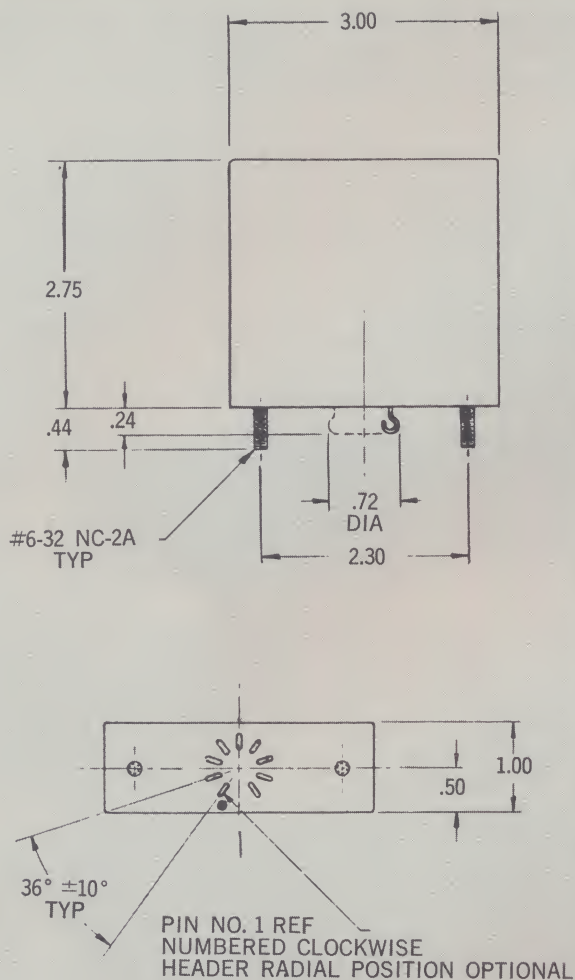


Figure 8

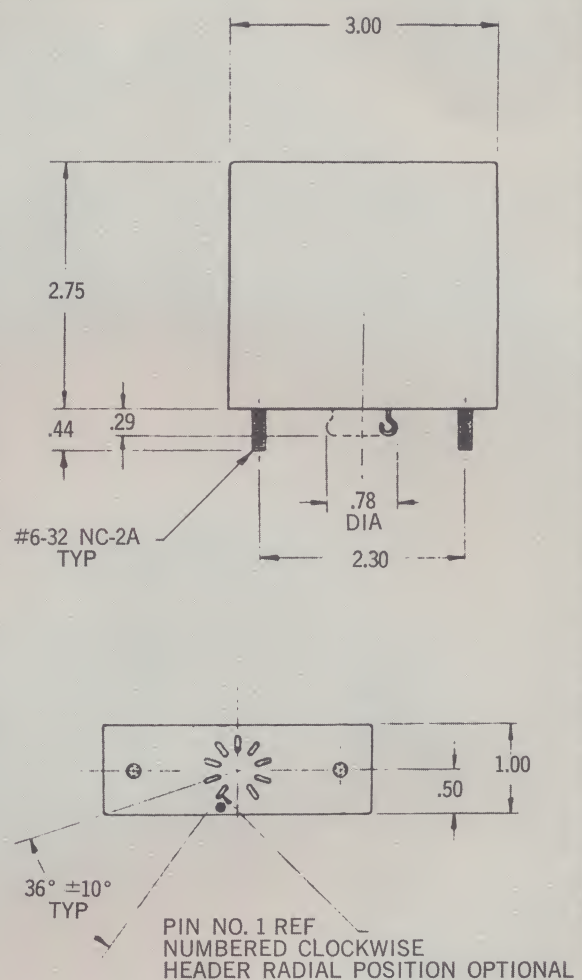


Figure 9

4.2 Gearing

AEI can provide gearing units as part of the motor package to meet specific applications.

Any number of conditions may dictate the desirability of a gearing unit. A few typical conditions are as follows:

- Extend the torque capacity of the motor.
- Alter the step angle of the motor.
- Alter the equivalent RPM output of the motor.
- Match the load inertia to rotor inertia.
- Modify the nature of the movement of the operating shaft and many other conceivable conditions.

The desirability for a single motor-gear package frequently simplifies the design of the ultimate equipment and can reduce the cost of same materially.

In supplying a motor-gear package an analysis of the ultimate application is usually made that enables the selection of a proper unit.

5.0 APPLICATION

Stepper Motors have found favor in numerous military, space, industrial and commercial applications. Their use in various servo, digital and positioning devices has resulted in overall simplicity, economy, and reliability of equipment.

Stepper motors have been applied in a long array of various control systems and equipments, of which the following are but a few typical examples:

- (a) Positioning of pens on X-Y plotting boards for ship, aircraft, industrial or research uses. Typical among these are ship-positioning, map-display, curve plotters (as magnetization curves etc.), data plotters, photo reproduction etc.
- (b) Tape and paper driving and recording mechanisms, where digital problems are considered.
- (c) Positioning of mirror or lens devices in various recording and follow up systems.
- (d) Digital tuners for klystron and doppler applications.
- (e) Analog to digital conversion and display systems.
- (f) Positioning of operating tables on industrial machinery — as milling machines etc.
- (g) General positioning of recording pens in recorders.
- (h) Valve positioning applications in numerous areas of industry.
- (i) Pulse signaling devices.

In selecting a suitable stepper motor for a particular application, a decision or an estimate must be made as to the load torque and moment of inertia desired, pulsing speed, whether operation is to be unidirectional or reversible, available operating voltage and such pertinent details outlined as possible variables in our data sheets.

In any event, discussion of potential applications with our engineers is welcomed. They will be pleased to assist in analyzing the specific problem and making appropriate recommendations to suit the particular requirements.



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